Biomechanics
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Lecture – 71
Enslaving Effects in Finger Force Production - 2

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Enslaving effects in multi-finger force production

Zatsiorsky VM, Li ZM, Latash ML. Enslaving effects in multi-finger force production. Experimental brain research. 2000 Mar;131:187-95.

(FL) Welcome to this video on biomechanics. In the previous video we were looking at the Zatsiorsky paper on enslaving effects in multi-finger force production, alright. So we were looking at the experimental methods.

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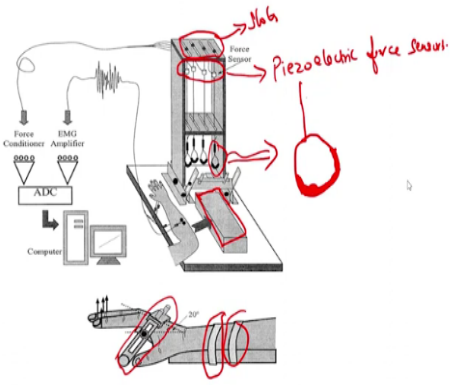
Zatsiorsky et al. (2000)

- **Objective:** When FDP, FDS, and INT were differently activated, what is the relative contribution of peripheral and central neural factors to the EE in multi-finger tasks?



Zatsiorsky, V. M., Li, Z. M., & Latash, M. L. (2000). Enslaving effects in multi-finger force production. *Experimental brain research, 131*(2), 187-195. https://doi.org/10.1007/s002219900261

Remember that the task involved placing different segments of the finger are the joints of the four fingers in four different loops and producing force with the instructed finger or finger combinations.

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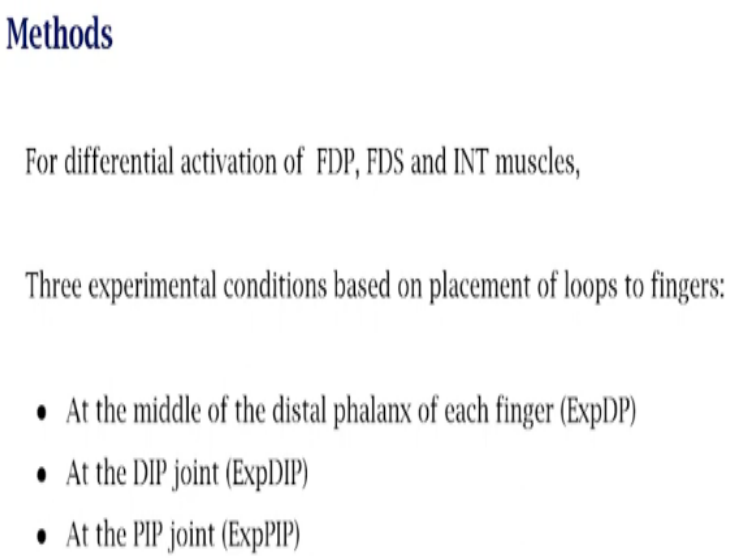

Either you place just with the distal phalanx or with distal interphalangeal joint or with the proximal interphalangeal joint.

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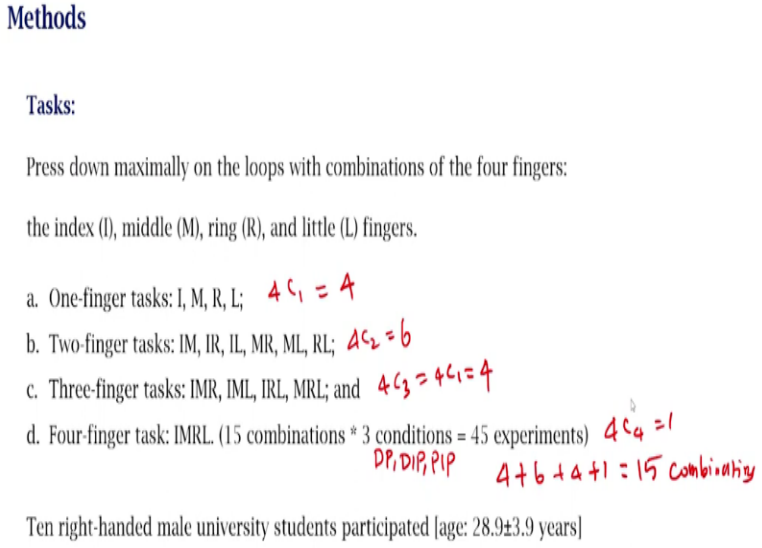

And there were 15 different tasks those that involved single fingers or one finger at a time and those that involve two fingers at a time, those that involve three fingers at a time and those that involve all the four fingers. And in each of these combinations or for each of these combinations they performed the task with the finger either in the distal phalanx or the DIP

joint or the PIP joint, so there will be 45 different experiments or 45 different possible combinations of trials that are possible.

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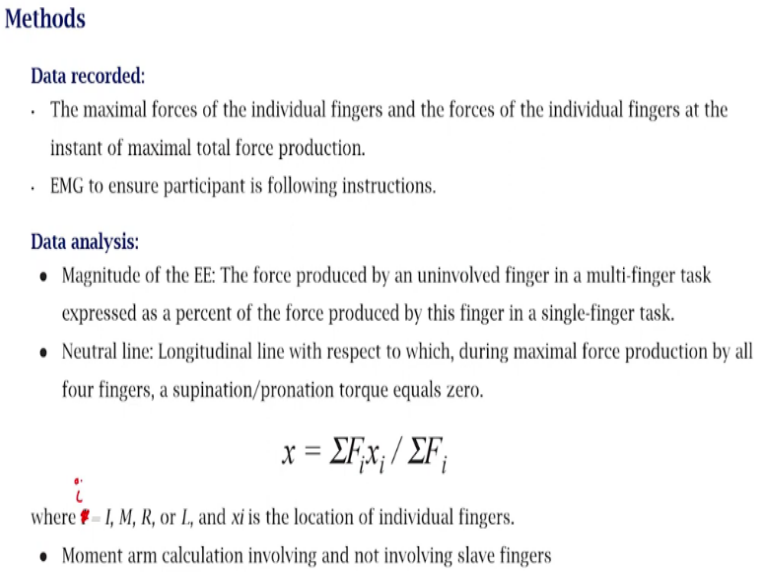

So in this video we will be looking at the data that is collected and the method of analysis that they used. So they asked the people to press as hard as possible with the instructed finger. At the same time they measured all the forces of all the fingers at the instant of the maximum force produced by the instructed finger, at the particular time when the maximum force is produced by the instructed finger they measured all the finger forces.

They also measured EMG to make sure that the participant is indeed following the instructions. If they are following the instructions, there will be no active force that is produced. If they are not producing active force with the non-instructed fingers that means they are following instructions. What is instruction? The instruction is not to worry about the other non-instructed fingers. If they are producing active force with the non-instructed fingers or the slave fingers, if they are producing force that means that they are not following instructions.

So the authors they measured the EMG and they compared it with baseline. If the EMG for the non-instructed fingers is comparable to baseline that means that people have followed the instruction. If they have actively produced force, then the EMG level will be higher than the baseline, this is the idea, this is the principle that was used to make sure that participants indeed follow instructions. And to analyze the data they took a few things.

First they measured the magnitude or they computed the magnitude of the enslavement effect. They found the force produced by a non-instructed finger or the uninvolved finger, uninvolved means all the fingers are involved what they are saying is that the non-instructed finger in a multi finger task, they expressed it as the force produced by that finger in their single finger task. They compare the force produced by a given non-instructed finger in a multi-finger task.

And compare it with the force produced by that finger in single finger task. Then they also computed the longitudinal line with respect to which during maximum force production by all the fingers, supination pronation moment equals 0. When I am producing more force with the ring or little fingers, the torque will be such that my hand is supinating, it is supinating. When I am producing more force with the index and middle fingers the torque will be such that as if it is pronating.

This supination pronation torque will be equal to 0, what is the line with respect to which this pronation supination torque is 0, depending on that location so they are interested in identifying that location x where this is not capital I, this is small i is I, M, R, L and xi is the individual finger's location and they tried to compute the momentum of this moment, this pronation supination moment they tried to compute the net momentum for that total moment with and without involving the slave fingers.

If you involve the slave fingers what is the momentum? If you do not involve the slave fingers what is the momentum? This will give you an idea of the amount of force that is produced by the non-instructed fingers. This is the analysis that they did.

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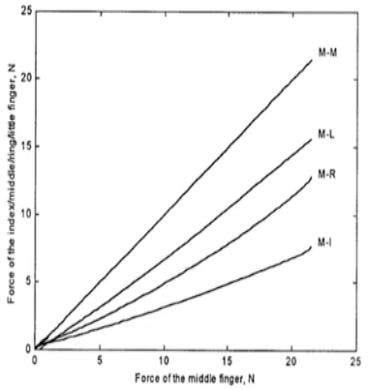
Results

- Parallel increase of master and slave force
- No perceptible threshold for enslaving force production



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Here as an example what they found was that they plotted the force of the middle finger and the force of the index, middle, ring and little fingers. They plotted this and they found that there is an increase of force in both the slave fingers and the master finger. There is a concomitant increase or a parallel increase of master and slave finger forces and it did not seem like there was any particular threshold after which enslavement force begins on this. So there is no particular threshold for enslaving force production that is what they found.

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Results

Example: I = 40N ("I" only)
IM = 35N (I contribution in IM task) (65N)

Two evident factors:

Force deficit: In multi-finger tasks, the peak forces of individual fingers were smaller than their maximal forces generated in the single-finger MVC trials.

Enslaving: Uninvolved fingers produced a substantial amount of force.

Also one more thing that we define is the force deficit, what is this? What they found was that in multi-finger force production tasks, the peak force produced by individual fingers were smaller than the maximum force generated in the single finger tasks MVC trials. That is let us say I am producing individually I am asking a participant to press as hard as possible with just the index finger, let us I am measuring 40 Newton's for example.

This is an example, so do not quote me on this. Let us say the index finger produces 40 Newton's in a single finger task, I only task, only the index finger alone is performing and this is what they are doing. Now suppose I am asking 2 two fingers to produce force, index and middle finger. This will be about 65 Newton's for I and M, in this the index finger alone will produce 35 Newton's, I contribution in I M task.

In both the cases, the fingers were instructed to produce maximum. When index finger is working in tandem with the middle finger why is it not able to achieve its maximum, individual finger maximum of 40 Newton's, earlier it produced 40 Newton's alone. When it is working with the middle finger it is only producing 35 Newton's, middle finger is producing 30 Newton's for example. So that means the peak forces of individual fingers were smaller.

It reduces than their maximum force that they generated in single finger MVC trials. So their contribution to maximum force in a multi-finger task is less than their own individual finger MVC trials. There is a reduction in their maximum when they are working with other fingers when compared with when they are working alone. This reduction is called as force deficit. The other factor is called as enslaving.

This is when the uninvolved fingers produced a substantial amount of force done. The uninstructed, non-instructed fingers when they produce a substantially large amount of force.

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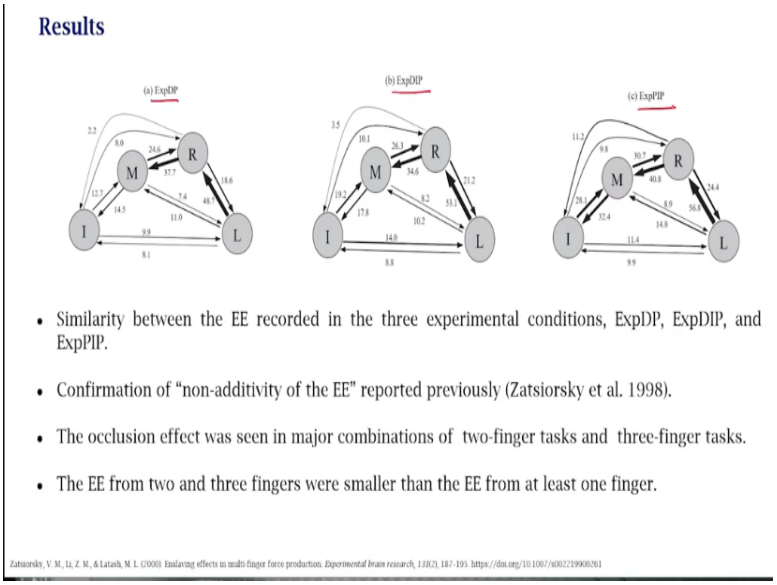

Remember our goal is to compare the amount of enslavement depending on the muscles that are involved. Whether the muscle involved is only for the distal phalanx or only for the DIP joint or only for the PIP joint that is the goal. So what was found was that in the three conditions between ExDP, ExDIP and ExPIP that is depending on where you place the fingers, whether you place it in the distal phalanx, whether you place it in the DIP joint and the PIP joint.

Depending on that if there is a difference depending on the experimental condition that means the individual muscles do contribute to enslavement in a big way that is the working hypothesis, is it not? But what they found was that there was no big difference between the three experimental conditions that were used. So it is not like whether you are using the extrinsic muscle or whether you are using the intrinsic muscle has any big difference in the enslavement.

That is somewhat surprising because extrinsic muscles send their tendons from the forearm and we assume that some of the enslavement might be due to intertendinous force transmission and other such things that we discussed in the previous weeks, is it not? If that is the case then you would expect those tasks that involve extrinsic muscles to have a greater amount of enslavement when compared with those tasks that only involve the intrinsic muscles.

Because the intrinsic muscles do not share tendons, but that is not what is happening. Then that means it is not merely the mechanics that plays a role or mechanical effects are playing slightly lesser role when compared with neural factors is the inference that we can get. They also confirmed that enslavement effect is nonadditive as was reported previously by Zatsiorsky and colleagues. Also, the occlusion effect was seen, I described what is occlusion effect.

The occlusion effect was seen in major combinations of the two finger tasks and three finger tasks and like I said the enslavement effect from two on three finger tasks were smaller than the enslavement effect from at least one finger. So, single finger enslavement effect is much greater than multi-finger enslavement effects. Occlusion effect was confirmed, nonadditivity was confirmed and the enslavement effect from multiple fingers is smaller than the enslavement effect from at least one single finger.

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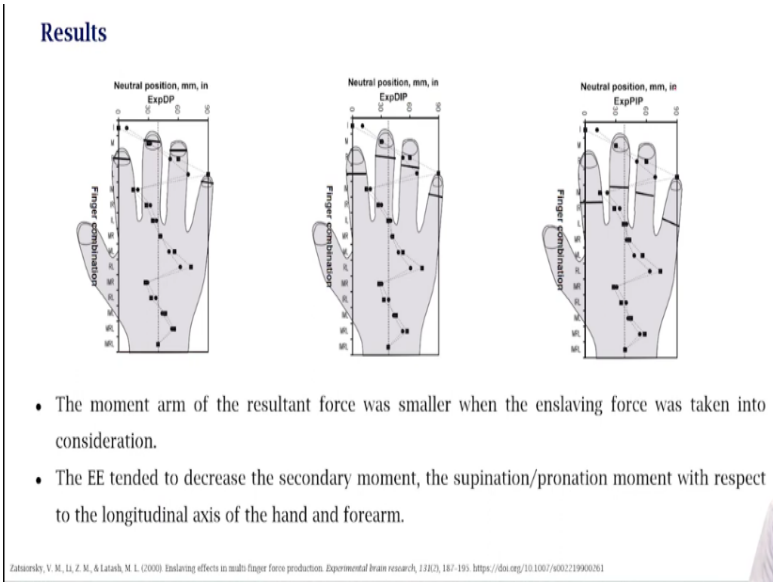

Also the moment arm of the resultant force was smaller when the enslaving force was taken into consideration. So if you are considering the noninvolved or the non-instructed fingers the moment arm of the resultant force reduces. So that means that the enslavement effect it appears to decrease the secondary moment, the pronation supination moment with respect to the longitudinal axis of the hand and the forearm.

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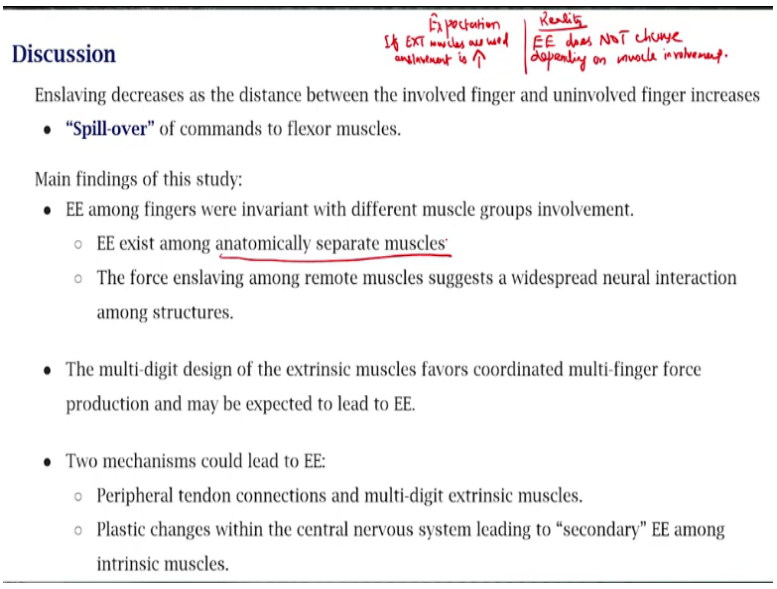

It seems like enslaving decreases as the distance between the involved finger and the noninvolved finger increases, this is also an extension of the previous result. So if you are far away from the involved or instructed finger then that means that the enslavement effect is lower. If you are next, if you are neighbour of the instructor finger then the enslavement effect

is more. This might be because of spillover of commands sent to the flexor muscles, this is a hypothesis.

The most important finding, the most important result from this study is that the enslavement effect between fingers did not vary depending on which muscle was involved in that task. If I was involving the extrinsic muscle, my hypothesis was that because the tendons are passing through or are moving close to each other there might be some form of intertendinous force transmission or some form of mechanical coupling that might lead to enslavement was the working hypothesis.

If that was the case if I do not use the extrinsic muscles in some tasks like we did in the experiment, in some tasks for example the ExPIP task only the intrinsic muscles were used, the intrinsic muscles do not share a common tendon. Each finger has its own intrinsic muscle. In that case we expect to have less amount of enslavement when compared with those tasks that involve use of the extrinsic muscle, this is the expectation.

So expectation, reality we will draw this. Expectation if extrinsic muscles are used enslavement is more, enslavement is higher. Reality enslavement or rather EE enslavement effect does not change depending on muscle involvement. In my opinion this is the most important result from the study what this implies, what is the inference, what is the meaning of this? The meaning of this is that enslavement is not merely a mechanical phenomenon as was the hypothesis.

That is hypothesis one for us that it is shearing between the tendons that is casing the enslavement. It is this intertendinous force transmission that is causing this enslavement. This mechanical coupling that is causing this enslavement. These are the things that we said as the first hypothesis. If that become true then in those tasks that only involve the intrinsic muscles that there is no such intertendinous force transmission, there is no mechanical coupling, there is no shearing.

In those cases enslavement must be less, but that is not what is happening. Enslavement does not change depending on which muscles are involved. That means that enslavement is not merely due to mechanical effects, it appears like enslavement is perhaps more of a central

origin, is more of a central phenomenon, is happening somewhere at the neural level or more of it can be explained by using neural factors than using mechanical factors.

At least this is something that we can state, more of enslavement is explainable using neural factors than mechanical factors. So enslavement effect exists among anatomically separate muscles such as the lumbricals, such as the intrinsic muscles like lumbricals, interossei, of course this study only involved flexion, just saying what are the intrinsic muscles thenar, hypothenar, lumbricals and interossei.

So the force enslaving among remote muscles between two lumbricals for example between the index finger and little finger in the ExPIP task, if it is two lumbricals that are far away from each other why are they enslaved, maybe there is some form of neural interaction that is happening. Also one more reason is that we would of course assume that this multi-digit design of the extrinsic muscle.

Were one motor unit gives rise to multiple tendons or one motor unit or fibers from one motor unit attaches to different tendons supplying different digits may cause to lead to enslavement effect. So essentially either peripheral tendon connections and multi-digit extrinsic muscle could lead to enslavement effect or plastic changes within the central nervous system leading to this secondary enslavement effect among intrinsic muscles.

So now we have some idea of the origin of enslavement effect. Now we can say as to why the musicians are able to unlearn enslavement because if it is neural in origin then learning and unlearning is a neural process, this is perhaps one of the reasons why the expert musicians are able to unlearn enslavement or able to learn finger independence, not interdependence. Finger interdependence is what typical people have, expert musicians have finger independence.

So they have unlearned enslavement, they have learned finger independence this is because perhaps enslavement is more of a neural process, perhaps something to think about it.

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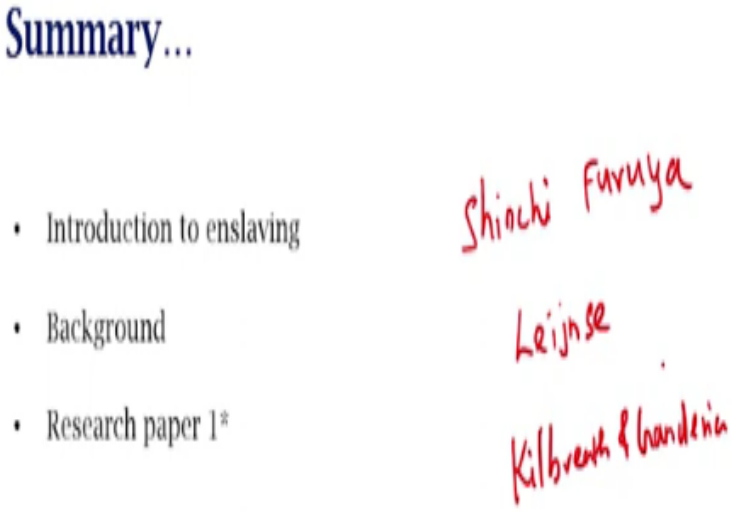

If you are interested in understanding more about how musicians use their fingers, I suggest you read the papers of this person, Japanese person Shinichi Furuya, he is a Japanese researcher, extensive work on musicians and their finger performance. Anyone who wants to study musicians and their finger performance should do a thorough study of Shinichi Furuya's work before starting out any new work.

There is also these classic studies by Leijnse, I do not know how to pronounce this, Leijnse I suppose, who has also performed some excellent experiments involving enslavement. Of course, there are the other standard studies by Kilbreath and Gandavia. Then they study on kinematic enslavement by Ross and Schieber which we will discuss in a future class. So in this video we looked at what is enslavement and we looked at the background to the research study and enslavement.

We discussed the 1998 paper and its major results on enslavement and then we discussed the first research paper which is the paper by Zatsiorsky, Zong-Ming Li and Latash published in the year 2000. We discussed the background and introduction for that. We discussed the methods in good detail. We discussed the major results and we also looked at what these results mean or the inference from these studies.

The major takeaway from this is that enslavement is perhaps **a** more of a neural factor than a mechanics based factor. So again, another example of how structure and function are related throughout this course this is the theme that we are interested in structure function

relationships. Well with this, we come to the end of this video. Thank you very much for your attention.